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TRANSPORT MODELLING OF FREIGHT FLOWS IN ACCORDANCE WITH INVESTMENTS: CASE STUDY OF SLOVENIAN RAILWAYS

ABSTRACT

Using specific scientific methods and through a model, the paper determines how investments in the railway infrastructure influence the whole railway system. The research is based on experience and on the results that have been found out in Austria, Argentina, Bolivia, Brazil, Chile and Venezuela. Based on scientific studies about the conditions of the Slovenian railway system, on the Methodology for determination of the investment measures and definition of conditions for a justified realisation and on the Calculation of the expected number of freight trains, the results that confirm the hypothesis of mid and long-term positive effects of investments in the railway network are given.

KEY WORDS

investments; freight transport; railway network; economic environment;

1. INTRODUCTION

Slovenia has a specific geographic position in the wider European area. That is why her transport system and her equilibrate development represent an important fact for further development. The railway subsystem is in very bad condition, because the investments in its maintenance, upgrade and new construction have been very poor in the last 30 years.

The main goal of the Slovenian transport policy is the development of a proper, efficient and balanced transport system. Such system could guarantee a high level of sustainable mobility, an appropriate protection of the environment and an efficient use of energy. In the last 20 years Slovenia has invested the major part of her economic resources in the construction of road network, particularly in motorways. The development of other transport modes has been totally neglected. This fact has caused an extreme burdening of the roads with goods transport. The railway system has lost its competitive advantages in terms of external costs, as well as the quantity of transported goods, safety and protection of the environment.

The purpose of this paper is to study the possibilities of rail transport subsystem development, based on official documents of the Ministry of infrastructure and spatial planning. The article is limited to the railway line that connects the Port of Koper to the Slovenian hinterland. The research subjects are the analysis and modelling of rail transport demand and the analysis of railway capacity on the chosen railway lines in Slovenia.

In the paper the following problems have been considered:

- past railway freight flows,
- what future rail freight flows are likely to be,
- which mid-term and long-term upgrades and modernisations are needed to assure the capacity of the railway network, the preservation and growth of the market share of the railway transport, and
- economic evaluation of planned investments on the chosen rail district (Divača – Koper).

Based on different foreign studies and on the result of the presented model, positive impacts on economy, logistics sector and on external effects could be expected. However, the condition is that the planned investments are realised.

Several studies [1] on this topic have been carried out in the world. The most recent ones have been made in Austria and in five States of South America.

The Austrian model [2], called EAR (economic accessibility and regional model), evaluates the investments in infrastructure. It is based on a dynamic spatial-econometric model, which makes long-term predictions possible. This model is based on data from the period 1995-2005 for 99 Austrian regions (or political districts). With it the modelling of local economic growth as a function of infrastructure, local economic and demographic indicators and traffic accessibility could be calculated. With the mentioned model a 30-year forecast has been made.

The described model has shown the following effects of investments in the rail network:

- the connection between investments in rail infrastructure and freight transport growth is middle-strong,
- in regions where the transport connections are good, the GDP is higher, consequently the employment level and the number of economic subjects are higher,
- growth of GDP in adjacent regions influences the growth of economic subject in the considered region.

The Latin American model [3] has taken into consideration five States – Argentina, Bolivia, Brazil, Chile and Venezuela. It shows macroeconomic effects of investments in public infrastructure. A dynamic stochastic model has been developed for calculating positive effects on consumption, private investments, trade balance and general welfare. The following effects of investments in the rail network in South America have been found:

- the growth of public investments in the infrastructure of 2% brings a growth in GDP between 4.7% and 6.63%,
- economic growth is directly connected to the growth of investments in public network,
- consumption, investments of private capital, work and salaries grow up for a certain period, and then they start to decrease – in the dependency of the start-up public capital.

Even if the two models seem comparable, the model used in Latin America is hardly possible to be implemented in Slovenia. With an accurate analysis of the two models it has been proved that the Austrian model is more suitable for application in Slovenia, because of the State dimensions, European and state legislation, economics, land configuration, traffic demand and other indicators that are mostly similar in the two States.

2. OVERVIEW OF RAILWAY TRANSPORT FLOWS IN SLOVENIA

Looking at railway freight flows in Slovenia in the past 20 years, a drop of 2.3% per year has been seen. On the other hand, the analysis of the railway freight transport in ton-kilometres shows a different picture. The growth of this index has been more or less constant in Slovenia and in the neighbouring States. The reasons could be found in the growth of the average journey of shipments between the dispatcher and the recipient and in changed relations and directions of goods transport.

The percentage of the shares of rail freight transport in the total land transport shows a different picture. In EU this share has decreased by several percentage points in the first ten years (1992 – 2002), and has stayed on the same level in the next ten years (around 19%). In Slovenia, on the other hand, this share was 18% in the year 2008. But there was a drastic fall from the year 1995, when this share was 50%. *Table 1* shows the structure of railway freight transport in the year 2012. The main part is represented by the international transport, with almost 89% of all railway freight transport in Slovenia. The international transport is divided mainly between port transit and international goods transport in import [1].

In the last years a change in the shares of freight transport could be noticed. It should be pointed out that, if the percentages are better, absolute values have dropped because of the crisis. *Table 2* shows the data for the period 2008 – 2012, both for tons and ton kilometres.

The dispatchers that sent the biggest quantities of goods in the year 2012 were freight station of Koper (27.5%) and Port of Koper (21.1%) [5].

Table 1 - Structure of rail freight transport in tons and in ton-kilometres in the year 2012

Transport freight in t (year 2012)					
Inland transport	International transport (1,000 t)				
	Import	Export	Land transit	Port transit	Total
140.4 (10%)	421.2(30%)	16.5, (12%)	252.7 (18%)	421.2(30%)	1,404 (90%)
Transport performance in tkm (year 2012)					
Inland transport	International transport (million tkm)				
	Import	Export	Land transit	Port transit	Total
279.5 (10%)	3,633 (30%)	335 (12%)	503 (18%)	3,633 (30%)	2,795 (90%)

Source: Analysis of possibilities and needs of development of public railway infrastructure in the Republic of Slovenia, 2011[1]; Statistical Office of the Republic of Slovenia [4]

Table 2 - Railway freight transport in Slovenia for the period 2008 – 2012

	National transport		International transport			
	Total		Total	Loaded in Slovenia	Unloaded in Slovenia	Transit
1,000 t						
2008	17,271	3,998	13,273	5,591	4,349	3,333
2009	13,774	3,301	10,473	4,266	3,817	2,389
2010	16,234	3,520	12,714	5,290	4,507	2,917
2011	17,024	3,320	13,704	6,328	4,619	2,756
2012	15,828	3,347	12,481	5,894	4,402	2,185
million tkm						
2008	3,520	740	2,780	1,316	691	773
2009	2,817	587	2,230	996	692	541
2010	3,421	617	2,803	1,286	835	682
2011	3,752	633	3,119	1,529	930	660
2012	3,470	668	2,795	1,404	850	541

Source: Statistical Office of the Republic of Slovenia [4]

3. DESIGN AND PURPOSE OF TRANSPORT MODELLING

Transport models offer support for the European and national projects of strategic decision and of long-term planning. One of the largely used ways of making a transport model is the so-called four-step model, presented in this chapter. The data for this model have been acquired from two main technical sources: Handbook of transport modelling [6] and literature from the Faculty of Civil Engineering in Maribor, Transport modelling [7]. Projects as TRANS-TOOLS (2005 and 2008) [8], TENconnect (2009) [9] and TRANSvision (2009) [10] have also been considered.

Internationally recognised software tool for the calculation of the described model is PTV VISUM [11]. It is used by the Institute of Traffic and Transport Ljubljana l.l.c., which has been the leader partner in the preparation of the main analysis on network investments in Slovenia [1]. PTV Visum [11] is the world's leading software for traffic analyses, forecasts and GIS-based (Geographic Information System) data management. It consistently models all road / rail users and their interactions and has become a recognized standard in the field of transport planning. Transportation experts use PTV Visum to model transport networks and travel demand, to analyse expected traffic flows, to plan public transport services and to develop advanced transport strategies and solutions. PTV Visum allows the distribution of calculation of several scenarios of a Visum project across multiple computation nodes. Additional accelerated procedures include:

- trip distribution of 4-step model,
- fare calculation in public transport,
- line cost calculation,
- timetable-based assignment [11].

3.1 Sub-models of four-step transport model

There are four phases or sub-models of this model: generation, distribution, selection of the transport means and burdening of the transport network.

The purpose of the first phase, called generation, is to determinate the total number of performed carriages of the analysed system. In this part the purpose is to make a connection between the average socio-economic characters of a specific area and the number of carriages, produced from or attracted by the considered area.

In the phase of distribution, data about the area of origin and of destination of the goods are obtained. The sub-model of distribution, through the production P_i and attraction A*j*, determines the O/D matrix T*ij* (called also origin-destination or journey matrix), for every type or purpose of goods transport [12]:

$$T_{ij}^{n,k,t} \tag{1}$$

which determines the transport of goods from area (*i*) to area (*j*) with purpose (*n*), transport means (*k*) and in time period (*t*).

There are usually two methods of data collection for journey matrices:

- empiric, where transport of goods is measured through inquiries, counting or observation, and
- synthetic, where expected freight transport is calculated, based on areas data.

As shown by international studies [1], the following data have to be collected:

- empiric data of freight traffic in national transport,
- amount of transported goods (in tons),
- number of freight vehicles on specific section (average daily yearly traffic), and
- empiric data of freight through national borders and goods transit.

Models of transport means selection can be divided into bi-modal (where there is a choice between two different transport means) and multi-modal, where numerous transport means are used [13]. In the fourth step transport offer is included, ment as infrastructure, superstructure, services... It is a combination of:
- passage of railway network,
- locations of railway stations,
- valid timetable and frequency of journeys,
- railway lines speed, and
- transportation and permeability performance of connections.

The final steps of each model are the calibration and validation, because of deviation between calculated transport flows and collected empiric data.

3.2 Railway transport model

The matrix for railway transport has been elaborated on the basis of all origin and destination stations in the year 2011 [1].

When the data of the basic O/D matrix and realised amount of transport have been compared, a calibration of the matrix has been made, (*Figure 1*), using the »O/D matrix calibration« process [11].

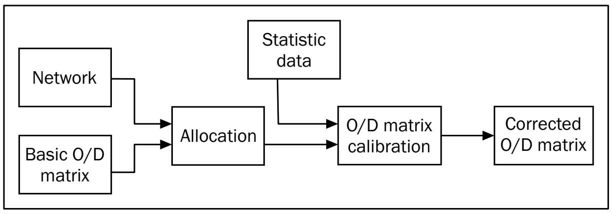

Figure 1 - Calibration method of an O/D matrix [11]

Source: own design, based on PTV Visum User manual, January 2011

3.3 Transportation performance of the network

Transportation performance of a line means that a specific line district, in a certain period, with the existing technical equipment of the line, specific type and series of trains and with the existing traffic organisation of trains, is permeable for a specific number of pairs of trains. It is expressed in the number of train, which can drive on a specific line district in a specific period. It considers real technical devices and transport technology, assuring the needed quality of the transport.

There are several methods for calculating the transportation performance of railway lines. The most used is the method, recommended by the International Railway Union (UIC) and described in the publication UIC 405 [14].

The permeability of a line or of a line district »N« is calculated by the following equation:

$$N = \frac{1,440}{t_{sm} + t_r + t_d} \tag{2}$$

where:

N – permeable capacity of a line, expressed in the number of trains,

t_{sm} – minimum average interval of train trail,

t_r – spare time,

t_d – extra time as a result of other districts.

Spare time t_r is an additional time, which is added to the smallest interval, limiting the consequences of train delays on the smaller possible number of trains. The UIC methodology sets that acceptable theoretical permeable capacity of a railway line can be between 33% and 67%. The equation for calculating the spare time is:

$$t_r = k \times t_{sm} \tag{3}$$

where:

k – variable constant (from 0.33 to 0.67)

Extra time t_d is the time, which runs after every small interval between two trains, to guarantee the quality management of traffic on the entire railway line. Observations made at UIC 405 [14] have shown that on approximately 40 line districts, with different number of stations in the district, the best extra time is 0.25 minutes for every train and district. The equation is:

$$t_d = 0.25 \times a \tag{4}$$

where:

a – number of station spacing on a railway line.

3.4 Transportation capacity

Transportation capacity of a railway line describes the capacity of a line to transport a particular quantity of goods. It considers the specific time, appropriate technical equipment, specific type of traction and valid organisation of railway traffic. This capacity, expressed in net or gross tons, is calculated with the following equation:

$$P_{\max} = \sum_{i=1}^{n} (N_T^i \times Q_{\max}^i) \times k_n \times k_q \times D \tag{5}$$

where:

$P_{\max}$ – transportation capacity in net tons per year,

N_T^i – number of i-type trains, which could pass through within a determined period,

$Q_{\max}^i$ – maximal permissible gross weight of the ith freight train,

k_n – coefficient of unevenness in the observed period,

k_q – coefficient of net mass,

D – number of working days of a year, when the line is accessible.

The coefficient of unevenness shows the relationship between the average and the maximum value of traffic in the considered period.

The coefficient of net mass shows the ratio between net and gross ton kilometre of specific train types and is used for calculating the net mass of a train.

4. EVALUATION OF FUTURE INVESTMENTS IN THE RAILWAY NETWORK

In the paper unified terms are used, as defined by the Slovenian law [15]. In this way the development measures are classified as reconstructions, upgrades and constructions.

4.1 Methodology for determination of the investment's measures and definition of conditions for a justified realisation

When measures for railway infrastructure improvement have been defined, several criteria have been taken into account. The most important is the exploitation of permeable potency of railway lines. It is represented as a ratio between the expected daily number of all trains and the permeable potency of the railway line. When the utilization of the capacity is higher than 85% for single rail and higher than 90% for double railway lines, the problems in managing the train traffic are expected. These problems cause instability of timetables (delays of trains) and negatively influence the traffic regime. When the utilization reaches or exceeds these values, the measures for increasing the potency have to be realized [16].

The permeable capacity of railway lines could be increased in several ways, and these are some of them:

1. organisation measures (reduction of the number of locomotive rides, link-up of trains, enlargement of train load, etc.),
2. upgrade of signal security, to guarantee train traffic in sheaves,
3. upgrade of transport spaces,
4. increase of railway line speed,
5. construction of new infrastructure.

In accordance with the project under reference [1], with the Resolution on National programme of public railway infrastructure development [17] and for the needs of preparing the starting points for economic justification of the investments, three alternatives were formulated, to be compared in the analysis:

- the »0« Alternative: measures which ensure »D category« conditions (axle load of 22.5 t), upgrades that started before the year 2008 and construction of new stations, based on the railway operator's plan,
- the »Z1« Alternative (limited investments), with investments that ensure sufficient capacity of main railway lines until the year 2020,
- the »Z2« Alternative (larger or big investments), that together with »Z1« alternative, includes investments which ensure sufficient capacity of the main railway lines until the year 2030 [17].

For the needs of this paper, only the investments on the railway line Divača – Koper and general investments on the network are considered. Investments in »0« Alternative include:

- modernization of security signal devices (SSD) on the railway line Divača – Koper,
- modernization of the existing railway line Divača – Koper,
- development of the ERTMS / ETCS (European Rail Traffic Management System / European Train Control System),
- introduction of digital radio system on the railway network.

The costs of the »0« investments (without VAT) are calculated at EUR 541 million [17].

Investments in »Z1« Alternative, that should be completed by the year 2020, include all the »0« Alternative measures, together with the construction of the new railway line Divača – Koper. The costs of the »Z1« investments (excluding VAT) are calculated at EUR 5,948 million [17].

Alternative »Z2«, to be concluded until the year 2030, includes all investments from »Z1« Alternative, together with:

- construction of a new double-track line Ljubljana – Divača, with the connection to the existing line [17].

The costs of the »Z2« investments (excluding VAT) are calculated at EUR 10,704 million [17].

4.2 Calculation of the expected number of freight trains

Modelling of transport phenomena needs a high level of understanding and knowledge of their features. It also needs concrete information about the past and present traffic flows. When there are temporal and space limits of data collection, information [17] have to be found from different, but relevant secondary statistic sources. Information could be divided into [8]:

- input data: socio-economic and demographic data, information on transported freight and passengers, data on transport network;
- information for calibration and validation: data about traffic count on specific routes and frontier points; and
- data needed for transport flows forecast, such as: expected GDP growth, expected motorization rate and expected demographic characteristic of the population.

The expected number of freight trains is calculated based on the expected amount of transportation performance and on prospective organisation of train operation. Freight trains could be divided into following groups:

- freight trains with gross mass lower than 1.500 tons,
- freight trains with gross mass higher than 1.500 tons (heavier freight trains),
- empty freight trains,
- locomotive trains,
- collecting and circular trains.

The expected number of freight trains (without empty and locomotive trains) is calculated based on the expected transportation performance, with the following equation:

$$N_t = \left(\frac{\sum_{i_1=1}^{n_1} Q_{i_1}}{Q_{i_1}^{povp}} + \frac{\sum_{i_2=1}^{n_2} Q_{i_2}}{Q_{i_2}^{povp}} + \frac{\sum_{i_3=1}^{n_3} Q_{i_3}}{Q_{i_3}^{povp}} + \frac{\sum_{i_4=1}^{n_4} Q_{i_4}}{Q_{i_4}^{povp}} \right) \times \beta \quad (6)$$

where:

N_t – expected total number of freight trains (without empty and locomotive trains),

Q_i^{povp} – average net mass of a freight train in the specific group,

Q_i – total net mass of the specific train group,

β – coefficient of unevenness of freight train number.

The coefficient of unevenness of freight train number is the relationship between the highest monthly number of freight trains and the average monthly number of these trains in the considered period. The data used for this calculation have been taken from the Information system of Slovenian railways, for the basic year 2011 [4]. In the calculation of the number of freight trains the average net mass of freight trains for specific line districts has been considered.

Regarding the expected number of freight trains on the future railway line Divača – Koper the hypothesis that has been made is that the masses of these trains will be similar to the existing ones.

The average gross masses of freight trains, which will run on the second railway line Divača – Koper have been taken from the study “Pre-investment design of New railway line Divača – Koper; section Divača – Črni Kal and section Črni Kal – Koper”, [19] where a simulation of freight train is presented (*Table 3*).

At this point it should be pointed out, that for the exact calculation all categories of trains (both freight and passenger ones) have to be taken into account. The number of passenger trains strongly influences the railway network capacity, as passenger train routes reduce the number of the freight ones. This means that the real freight transport on a considered route is smaller because of the increase of passenger trains. One passenger train could limit the transportation capacity of a railway line by some hundred thousand tons per year [1].

Net present value (NPV) is a formula used to determine the present value of an investment by the discounted sum of all cash flows received from the project. The formula for the discounted sum of all cash flows can be rewritten as:

$$NPV = -C_0 + \sum_{i=1}^{T} \frac{C_i}{(1+r)^i} \quad (7)$$

where:

$-C_0$ – initial investment,

C – cash flow,

r – discount rate,

T – time.

The formula for the relative net present value (RNPV) is:

$$RNSV = 100 \times NSV/I \quad (8)$$

where:

I – investment costs

The quotient of relative advantageousness or benefit-cost ratio (K/S) shows the comparison of the present value of an investment decision or project with its initial cost. A ratio of greater than one indicates that the project is a viable one.

Based on the above mentioned assumptions the following economically justified financial indicators on the main public railway lines have been calculated, for »Z1« Alternative, compared to »0« Alternative:

- *net present value (NPV) = EUR -2,372.21 million,*
- *relative net present value (RNPV) = -0.59,*
- *benefit-cost ratio (K/S) = 0.41*

All above-mentioned indicators of financial justification (NPV and RNPV) have negative values, or are smaller than 1 (K/S), which is not unusual for larger investments. Usually investments in railway network have negative effect and do not make profit for the

Table 3 - Yearly number of freight trains on the rail district Divača – Koper, considering different investment alternatives

No. of railway line	Name of the line	2011	2020 »0« alternative	2020 »Z1« alternative	2030 »Z2« alternative
60	Divača - Prešnica	18,320	19,481	7,104	8,692
60	Prešnica - Koper	17,521	18,687	6,310	7,660
	Divača – Koper (new)	0	0	661	840

Source: Analysis of possibilities and needs of development of public railway infrastructure in the Republic of Slovenia, 2011[1]; Statistical Office of the Republic of Slovenia [4] investor, but they are very important from the public point of view.

If the same calculation is made for »Z2« Alternative, compared to »0« Alternative, the results are:
- *net present value (NPV) = EUR -4,205.34 million,*
- *relative net present value (RNPV) = -0.71,*
- *benefit-cost ratio (K/S) = 0.29 [1].*

For investments in railway infrastructure the following financial sources could be considered [20]:
- state budget sources (sources from general budget of Slovenia; special sources for investments in railway infrastructure),
- non-refundable EU funds (resources from the cohesion fund; TEN-T financial sources),
- credits, and
- public–private partnership.

4.3 Results analysis

The analysis of expected social benefits and investment costs in the railway network shows that if the legal 7% discount is considered, the economic net actual value is negative. But it can be also found that the results will be acceptable, as NPV will result positive if the discount rate is 4.5%.

The results of the research have indicated that implementing the »Z1« version, the quotient of relative advantageousness (K/S) is 0.41. This ratio is even better for the »Z2« version, where K/S is 0.29.

If 3.5% discount rate (recommended by EU for this kind of investments) is considered, the expected benefits of the investments in railway infrastructure are higher than the expected costs. It can be confirmed that the planned investments of EUR 5,947 million by the year 2020 and EUR 10,704 million [1] by the year 2030 are socially justified.

5. CONCLUSION

With the scientific methods and models, used for transport flow planning, we have shown the expected effects of investments in the railway infrastructure on the transport system.

The existing railway lines in Slovenia were mostly built in the past century. The only line, which was built after Slovenian independence, was the railway line from Murska Sobota to the Hungarian border in 2001. All the remaining investments have been directed just for the preservation of transport capacity on an obsolete and inopportune railway infrastructure.

Based on the analysis the following hypotheses could be confirmed:
- transport infrastructure contributes to the economic growth and productivity,
- the elasticity of the transport infrastructure offer has a significant influence on the economic growth and development of a State.

Improvements in railway network should make Slovenian companies more competitive, because of the price advantages, if compared to road transport. The improvement of the railway network should bring the improvement of the quality of the railway transport services, in terms of average speed, punctuality, frequency and quantity. Positive effects could be expected in the logistics sector, too, as the increase of freight railway flows brings an increase in the logistic services demand. The investments in the railway infrastructure would influence the development of:
- basic logistic services, as railway transportation, intermodality, services of warehousing, distribution, and manipulation,
- complementary logistic services, as services of forwarding, insurance and control,
- additional logistic services, as parking spaces, fuel provision, and vehicle maintenance.

There is another aspect that has not been analysed in the present paper, but should be at least mentioned – the external costs of transport. The latest evaluations of these costs [15] for Slovenia are EUR 2.4 billion, which represents 7% of the Slovenian GDP. The costs of road freight transport are twenty times higher than the costs in the railway system.

There are several options of financial sources for realizing these investments: state budget sources (sources from the state general budget; purposive sources for investments in railway infrastructure), non-refundable EU funds (cohesion fund, TEN-T sources), credits and public-private partnership.

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POVZETEK

PROMETNO MODELIRANJE BLAGOVNIH TOKOV GLEDE NA INVESTICIJE: ŠTUDIJA PRIMERA SLOVENSKIH ŽELEZNIC

S pomočjo posameznih znanstvenih metod in postavljenega modela sva ugotavljala kako vplivajo investicije v železniško infrastrukturo na celoten železniški sistem. Pri tem sva upoštevala izkušnje in rezultate, ki so jih imele Avstrija, Argentina, Bolivia, Brasil, Chile and Venezuela. Na osnovi znanstvenega proučevanja razmer v slovenskem železniškem sistemu in s pomočjo metodologije za določanje investicijskih ukrepov in pogojev za ekonomsko upravičeno realizacijo ter z izračunom pričakovanega števila tovornih vlakov and the Calculation of the expected number of freight trains, sva prišla do rezultatov, ki potrjujejo postavljene hipoteze.

KLJUČNE BESEDE

Investicije; blagovni transport; železniško omrežje; ekonomsko okolje;

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